MANAV RACHNA INTERNATIONAL UNIVERSITY

Short Synopsis

For

Ph. D. Programme 2010-11

Title: Mixed Ion Conducting Composite Polymer Electrolyte for Electrochemical Devices

DEPARTMENT OF PHYSICS

FACULTY OF ENGINEERING & TECHNOLOGY

Submitted by:

Name: Sandeep Srivastava
Signature:

Registration No.: 10019990241
Email ID: sandeepsri1973@gmail.com
Contact No.: 9871982823

Supervisor:

Name: Dr. Pradeep K. Varshney
Signature:

Designation: Professor & Associate Director
Email ID: pradeep.fet@mriu.edu.in
Contact No.: 9560299049

MANAV RACHNA INTERNATIONAL UNIVERSITY
FACULTY OF ENGINEERING & TECHNOLOGY

Declaration

This is to declare that this short synopsis reflects the research work design and its contents are the original piece of work, as per guidelines, grammatically correct and free from plagiarism. This has been prepared under the guidance and supervision of my supervisor/joint-supervisor.

(Signature of Research Scholar)
Name : Sandeep Srivastava
Registration No. : 10019990241
Batch : 2010-11
Department : Physics

Certificate

This is to testify that the entire text of this Synopsis, prepared by my research scholar, has been read thoroughly and it is as per the guidelines and grammatically correct. Further, it is original piece of his/her work and free from plagiarism.

Signature of the supervisor
Name : Dr. Pradeep K. Varshney
Designation: Professor & Associate Director
Department: Chemistry

Recommendation

I recommend this short synopsis prepared and submitted by **Mr. Sandeep Srivastava** for approval of Ph.D Quality Enforcement Committee and thereafter to be uploaded on Shodh Gangotri.

(Dr. M K Soni)
Executive Director & Dean, FET, MRIU

ABSTRACT

The electrolytes are the lifeline of electrochemical devices and play an important role in the performance and applications of electrochemical devices. To characterize the ideal electrolyte for electrochemical devices, it requires a fundamental understanding of the molecular interactions in both the bulk electrolyte and electrode electrolyte interface. The Mixed-ion Composite Polymer Electrolytes (CPE) are solid systems in which two or more materials are mixed together to enhance the ionic conductivity at room temperature. The various mixed-ion composite polymer electrolytes have been developed and the present work is directed towards investigation of similar mixed-ion composite polymer electrolytes systems. The main objective of the proposed work is to prepare and characterize a new mixed-ion composite polymer electrolyte by using self-polymerization and solvent casting. A new series of mixed-ion composite polymer electrolyte films will be prepared by using photo-polymerization and other techniques with varying concentration of ionic salts or acids, plasticizers, monomers and copolymers. After the synthesis and optimization of parameters, these mixed-ion CPE films will be characterized using I-V characteristics, CV, XRD, FTIR & SEM techniques to know the suitable applications of these films in electrochemical devices.

Keywords: Electrolytes, Mixed-ion Composite Polymer Electrolytes, Ionic Conductivity, Photo- polymerization, Electrochemical Devices

CONTENTS

S. No.	Description	Page No.
1	Introduction	1-2
2	Literature Review	3-6
3	Description of Broad Area	6
4	Objective of the Study	7
5	Methodology to be adopted	7
6	Expected outcome of the research	8
7	Proposed Time Frame	8
8	References	8-13

Introduction

The scientific assessment of recent years provide us the information that the various electrochemical devices such as high energy density batteries, fuel cells, sensors, supercapacitors, smart windows and display devices are fabricated, based on polymer based solid electrolytes (Shekhon 2003; Tarascon & Armand 2001; Varshney et al. 2003; Varshney & Gupta 2011; Yang & Hou 2012). The liquid electrolytes were used in most of the conventional ionic devices in spite of their limitations like (a) short shelf life time period, corrosion reactions occurring between the electrolyte solutions and electrodes, leakage and instability towards the temperature variations. These limitations have initiated the interest to seek the possibility for new solid polymer electrolyte with higher ionic conductivity. In (the) last four decades, these electrolytes have been investigated. Because of the simple fabrication process, longer electrochemical stability and ability to form a proper interfacial contact with the electrodes, these are the potential candidates for use in electrochemical devices. Further the improvements were taken up in the area of conductivity, mechanical properties and electrochemical performance of these polymer electrolytes. One of the most promising ways to enhance ionic conductivity, mechanical strength etc. is insertion of mixed-ion species in solid polymer electrolytes (Aly et al. 2012; Neves & Fonseca 2004; Panero et al. 2007; Stephan & Nahm 2006).

In modern, diverse technological applications, many existing solids are in use whose ionic conductivity is high and of the order of 10^{-4} S/cm. Some of these good solid electronic conductors are referred as ‘mixed conductors’. These mixed-ionic conductors are also termed as ‘solid electrolytes’ as they are importantly used in battery applications. The solid electrolytes are more advantageous than liquid electrolytes in electrochemical devices which include longer shelf life, high energy density, less possibility of leakage etc., and are particularly suitable in compact power batteries used in pacemakers, mobile phones, laptops etc.

Mixed-ion Composite Polymer Electrolytes (CPE) are solid systems in which two or more materials are mixed together to enhance the ionic conductivity at room temperature. In this decade, mixed-ion high conducting polymers, which are known as solid polymer electrolytes (SPE), have been reported (Yang & Hou 2012). These mixed-ion SPEs are synthesized by dissolving the salt of alkali metals of type MX (M= Na, Li, Ag, Cu, etc) and (X= I, F, etc) in polymers like polyvinyl alcohol (Aji et al. 2011), polyethylene oxide (Chandra, Singh & Chandra 2002; Fahmi et al. 2012), polypropylene oxide (Song, Wang & Wan 2000) etc. These electrolytes are mainly classified as solvent free salt complexes, solvent swollen polymers and polyelectrolytes. These can be prepared in the form of bulk as well as in thin film (Yang & Hou 2012).

Lithium ion is the mobile carrier in the lithium mixed-ionic conducting compounds. The ionic radius of lithium ion is small compared to those of K^+ and Na^+ ions. Hence, lithium compounds are having a more conductivity than Na^+ & K^+ ion conductors. Lithium compounds are useful for high energy density batteries due to their high electrochemical potential. Some of the lithium ion conductors used are LiI (Lubben & Modine 1996), $LiCF_3SO_3$ (Yang et al. 2013), $Li_{1+x}Ti_{2-x}Al_x$ $(PO_4)_3$ (x=0; 0.3) (Kosova et al. 2008), $Li_{1.4}Ti_{1.6}Al_{0.4}(PO_4)_3$ (Takahashi et al. 2012), Lithium Aluminium Germanium Phosphate based glass-ceramic (Thokchom & Kumar 2008), Lithium Lanthanum Titanate Oxide/Polyacrylonitrile submicron composite (Liang et al. 2011).

Researchers have attempted many approaches for the fabrication of devices using different polymer electrolytes. In this context, several attempts have been made to develop composite polymer electrolytes and mixed-ion composite polymer electrolytes in film form for the ease of fabrication of device which eliminated the problems related to gel polymer electrolytes and solid polymer electrolytes (Agnihotry et al. 2004; Johan & Ting 2011; Lee et al. 2012; Pandey, Kumar & Hashmi 2010; Sreelalitha, K & Thyagarajan, K 2013; Tripathi & Shahi 2011; Zhang et al. 2011).

Literature Review

1. An Historical Survey

In 1800, Alessandro Volta, Professor at University of Pavia invented a device called “electric pile”, which revolutionized the era of energy production. The idea of this invention was based on Luigi Galvani’s experiments (the relationship between electricity and muscle contractions). This invention is considered as the birth of the Electrochemistry. At the end of the 18^{th} Century, the Electrochemistry was born as a Science.

In the modern technological world, the electrochemistry seems as an important part of Chemistry and combination of different materials provide the technical advancement in electrochemical cells. Also the new electroactive polymeric materials are in development phase with different lucrative properties such as electroluminescence, semiconductor behavior, electronic and ionic properties, electrochromism etc. The electrochemical cell is an arrangement of two immersed electrodes in electrolytes. The variety polymeric materials suggest the combination of different polymers in several components of such cells provides new opportunities of constructing high performance commercial electrochemical devices. Also the polymers are used as active electrodes (electronically conducting polymers), solid electrolytes (ionic conducting polymer) and as transparent substrates (optically transparent plastic electrodes) for optical/electrochemical devices.

The investigation of ion conducting solid materials begins after the Faraday's work on silver system in 1839 (Gray 1991). The interests of solid materials are due to high ionic conductivity comparable with those of liquid electrolytes, thus they are known as "Solid Electrolytes". The development and study of these materials were started actively about three decades ago, when the tremendous potential application of these materials was realized in various electrochemical devices. So far a number of excellent reviews are available (Aly et al. 2012; Souza & Quadri 2013; Srivastava & Tiwari 2009; Stephan & Nahm 2006, Varshney & Gupta 2011; Yang & Hou 2012).

Generally the ionic solids are insulators in the solid form and good conductors in the liquid state. The liquid state can be a melt as well as an aqueous solution. However, the solid

substances with high ionic conductivity and negligible electronic conductivity are discovered. The term solid electrolyte is justified to describe the solids having high ionic conductivity of the order of the liquid electrolytes. The short shelf life, leakage, instability towards temperature variation etc. are the some limitations of conventional ionic devices made up of Liquid electrolytes. To overcome these limitations, the search for other alternate has been initiated and come out well with reasonably high ionic conducting substances.

2. Electrolytes: ionic motion in polymers

The electronic conductivity is the phenomenon related to the electrons-holes movement into solid conductors, ionic conductivity is described as the charge movement due to the ion's motion. As the first applications regarding the electrical properties of polymers were directed to their insulating characteristics, ionic conduction in polymers was initially observed as an undesired property. However, this point of view has been changed by Wright and co-workers when they carried out the pioneering measurements of ionic conductivity in polymer-salt mixtures (Fenton, Parker & Wright 1973) and Armand and co-workers proposed the use of such systems in secondary batteries (Armand & Duclot 1979). Since that time, the research on solid polymeric electrolytes has grown intense and reviews with historic surveys have been published, the several attempts have been made to get a substitute of solid-state ionic conductors to the liquid electrolytes in several electrochemical devices. The major challenge into replacing the liquid or gel electrolyte by a polymeric one is to keep the high operating efficiency, similar to the electrochemical devices based on liquid junctions. Besides improving the stability of the active interface, allowing a long-term durability, a polymer electrolyte eliminates problems concerning evaporation or leakage of the solvent (Park et al. 2003).

The use of polymer in electrolytes can be divided to three categories, as follow: (a) a polymer swollen with a liquid electrolyte, which provides high values of conductivity, but does not eliminate the problems related to the liquid electrolytes; (b) a polymer containing cations or anions attached to the chain, which produces low conductivity values because of the low mobility of charge carriers; (c) a mixture of a salt (i.e. mixed-ions) in an ion-solvating polymer, that configures a dry and solid electrolyte system, can present conductivity values suitable for

using in electrochemical devices and eliminates all difficulties relative to the use of liquid or gel electrolytes in commercial applications.

3. Types of mixed-ion polymer electrolytes

Mixed-ion Composite Polymer Electrolytes is the synonym for heterogeneously doped materials or dispersed solid electrolytes. Conductivity enhancement in two-phase composite systems was known for about five decades (Rosseinsky & Malpas 1975; Shahi & Wagner 1982), however, the research activity in this area warmed up, when Lubben & Modine reported approximately 40 times enhancement in ionic conductivity of LiI at room temperature simply by dispersing ultrafine particles of inert Al_2O_3 in LiI (Lubben & Modine 1996). Since then, a large number of two-phase composite systems have been investigated with the conductivity enhancement of about one to three orders of magnitude compared with those of constituent phases (Agnihotry, Varshney & Sekhon 1999; Furusawa & Kawaguchi 2001; Lim, An & Jo 2012). The conductivity increases with increasing dispersoid concentration, attains a peak value, then decreases (Lee et al. 2012). The peak is generally sharp, except for few systems, such as HgI_2–Al_2O_3, AgI – pre dried Al_2O_3. Furthermore, the conductivity maxima may be different in different composite systems and depends on the nature of the second phase dispersoid. In some composite systems, dispersion has not altered/increased the conductivity of the host matrix. The nature of dispersoid decides the order of enhancement in composite electrolyte systems. For instance, highest conductivity enhancements were reported in AgI–Al_2O_3 and LiCl– Al_2O_3 systems with - Al_2O_3 dispersoid. In general, larger enhancements are reported with Al_2O_3 in many composite electrolyte systems as compared with other dispersoids (Shahi & Wagner 1982). The enhancement of conductivity in composite electrolyte systems is strongly dependent on particle-size of the dispersoid. It has been found that the conductivity of the composite system increases with decrease in particle size (Kumar & Shahi 1995). Temperature influences conductivity enhancement in composite electrolyte systems and the detrimental effect is observed at high temperatures. The high ionic conductivity has shown by AgI-doped mixed-ion conductor composites at room temperature (Takahashi et al. 2004). More recently, some researchers have attempted in the development of new solid electrolyte system involving, a number of compositional variations of AgI (Noorussaba & Ahmad 2012), CuI

(Saba & Ahmad 2012), KI and K_2SO_4 with ternary solid electrolytes [$CdHgI_4$] (Saba, Ahmad & ÖZÇELİK 2010), Cu_2HgI_4:0.2AgI with K_2SO_4 (Noorussaba & Ahmad 2011).

Among polymer electrolyte, proton & lithium ion conducting films are being extensively investigated to make them commercially viable. In modern technological era, where the product would be cost effective, light weight and efficient, now the researchers are seeking the possibilities to invent new blended composite polymer electrolytes. The mixed-ion conducting composite polymer electrolytes when blended with Ionic Liquid with Li^+ have been given remarkable results. The combination of Li^+ and different protonic agents like H_2PO_4 (Lee et al. 2008), H_2PO_3 (Li & Tang 2010), have been reported. The combination of Li^+ with $MgCl_4$, $ZnCl_4$ (Nagel et al. 2002), Sulphur for Lithium Sulphur battery (Manthiram, Fu & Su 2013), Polystyrene–Al_2O_3 composite for lithium secondary battery (Lim, An & Jo 2012) have been reported. The ionic conductivity in these system reported in the order of 10^{-2} - 10^{-3} S/cm at room temperature. Such high ionic conducting proton conductors/mixed-ion conducting composite polymer electrolytes can have vast applications in different electrochemical devices (ECDs) like fuel cells, smart windows electronic and optical devices, supercapacitors etc.

Description of broad area

Over the last four decades, the solid polymer electrolytes used as potential candidate for electrochemical devices because of the simple fabrication process, longer electrochemical stability and strong interfacial contact with electrodes. In spite of that, electrochemical properties like conductivity, mechanical properties and cell performance of existing polymer electrolytes may be further improved.

Currently used Li^+ mixed electrolytes are expensive, even though they have a good shelf life. The available electrolytes used in electrochemical devices are non-biodegradable. These limitations have initiated the interest to search for new mixed-ion composite solid polymer electrolyte with high ionic conductivity and other electrochemical properties. The development and production of mixed-ion CPE by various methods like self polymerization and solvent casting method are in progress and efforts are being made to.

Objectives of the study

The objective of the present work is directed towards the synthesis of new mixed-ion composite polymer electrolytes for electrochemical device applications.

1. To synthesize new mixed-ion CPE by taking different composition of polymers and ionic salts.
2. To study the electrical properties of the mixed-ion CPE by Impedance Analyzer.
3. To study the chemistry of mixed-ion CPE films like redox behavior, working potential range of the electrolyte and shelf life of the demonstrated samples using Cyclic Voltammetry (CV).
4. To determine the nature of CPE (amorphous or crystalline) by using X-Ray diffractometer (XRD).
5. To identify the chemical composition, chain structure and physical properties i.e. chain orientation, crystallinity and chain dynamics of the mixed-ion CPE films by using Fourier Transform Infrared spectroscopy (FTIR).
6. To study the surface morphology/micro structural morphology of the mixed-ion CPE films by using Scanning Electron Microscope (SEM).

Methodology to be adopted

The main objective of the proposed work is to prepare and characterize new mixed-ion composite polymer electrolytes by using self polymerization and solvent casting.

1. Selection of polymers and salts.
2. A new series of mixed-ion composite polymer electrolyte films will be prepared by photo-polymerization and chemical synthesis technique with varying concentration of ionic salts or acids, plasticizers, monomer and copolymer.
3. After the synthesis and optimization of parameters, these mixed-ion CPE films will be characterized by using I-V characteristics, CV, XRD, FTIR & SEM techniques to know the suitability of wide applications of these films in electrochemical devices.

Expected outcomes of the research

The expected research outcome of the proposed research work would be the availability of a scientific database containing design, characterization and fabrication of a new technique based economical mixed-ion CPE films and of technical data regarding their device applications. These self polymerized films contribute towards the requirements of economical electrochemical devices. The investigation results of proposed research outcome at every stage will be published in national and international journals in the field of Solid State Ionics. The proposed research outcome will also contribute towards the opening for new researchers.

Proposed Time Frame

Work / Time	1st Year		2nd Year		3rd Year		4th Year	
	Six months	Six months	Six months	Six months	Six months	Six months	Six months	Six months
Course work & Literature Survey	←	→						
Synthesis and optimization of parameters			←	→				
Characterization				←	→			
Analysis & Paper Writing					←	→		
Thesis Writing & Submission							←	→

References

Agnihotry, SA, Ahmad, S, Gupta, D & Ahmad, S 2004, 'Composite gel electrolytes based on poly (methylmethacrylate) and hydrophilic fumed silica', Electrochimica Acta, vol. 49, issue 14, pp. 2343-2349.

Agnihotry, SA, Varshney, P & Sekhon, SS 1999, 'PMMA based gel electrolyte for EC smart windows', Electrochimica Acta, vol. 44, issue 18, pp. 3121-3126.

Aji, MP, Rahmawati, Masturi, Bijaksana, S, Khairurrijal & Abdullah M 2011, 'Eletrical and Magnetic Properties of Polymer Electrolyte (PVA:LiOH) containing In Situ Dispersed Fe_3O_4 Nano particles', International Scholarly Research Network ISRN Materials Science, vol. 2012, Article ID 795613.

Aly, Ayman A, Zeidan, El-Shafei B, Alshennawy, AbdAllah A, El-Masry, Aly A & Wasel, Wahid A 2012, 'Fraction and wear of polymer composite filled by Nano particles: a Review', World Journal of Nanoscience and Engineering, vol. 2, issue 1, pp. 32-39.

Chandra, Amita, Singh, PK & Chandra, S 2002, 'Semiconductor-dispersed polymer electrolyte composites', Solid State Ionics, vol. 154–155, pp. 15–20.

Fahmi, EM, Ahmad, A, Nazeri, NNM, Hamzah, H, Razali, H & Rahman, MYA 2012, 'Effect of $LiBF_4$ Salt Concentration on the Properties of Poly(Ethylene Oxide)-Based Composite Polymer Electrolyte', International Journal of Electrochemical Science, vol. 7, issue 7, pp. 5798 - 5804.

Fenton, DE, Parker, JM & Wright, PV 1973, 'Complexes of alkali metal ions with poly(ethylene oxide)', Polymer, vol. 14, issue 11, pp. 589.

Furusawa, Shin-ichi & Kawaguchi, Takashi 2001, 'Ionic Conductivity of AgI Film on the SiO_2 Glass Substrate', Journal of the Physical Society of Japan, vol. 70, issue 12, pp. 3585-3590.

Gray, M Fiona 1991, 'Solid Polymer Electrolytes Fundamentals and Technological Applications', VCH, Weinheim.

Johan, Mohd Rafie & Ting, Lim May 2011, 'Structural, Thermal and Electrical Properties of Nano Manganese Composite Polymer Electrolytes', International Journal of Electrochemical Science, vol. 6, issue 10, pp. 4737-4748.

Kosova, NV, Devyatkina ET, Stepanov, AP & Buzlukov, AL 2008, 'Lithium conductivity and lithium diffusion in NASICON-type $Li_{1+x}Ti_{2-x}Al_x(PO_4)_3$ (x= 0; 0.3) prepared by mechanical activation', Ionics, vol. 14, issue 4, pp. 303-311.

Kumar, Ashok & Shahi, K 1995, 'Particle size effect on ionic conductivity in NaCl - Al_2O_3 composite solid electrolytes', Solid State Communications, vol. 94, issue 9, pp. 813-816.

Lee, Jin Woo, Khan, Sher Bahadur, Akhtar, Kalsoom, Kim, Kwang-In, Tae-Wonyoo, Seo, Kwang – Won, Han, Kaksoo & Asiri, Abdullah M 2012, 'Fabrication of Composite Membrane

based on silicotungstic heteropoliacid doped polybenzimidazole for high temperature PEMFC', International Journal of Electrochemical Science, vol. 7, pp. 6276-6288.

Lee, Kwang-Sei, Moon, Joonhee, Lee, Jisu & Jeon Minhyon 2008, 'High temperature phase transformations in LiH_2PO_4 and possible solid state polymerization', Solid State Communications, vol. 147, issue 1-2, pp. 74-77.

Lee, Yoon-sung, Ju, Seo Hee, Kim, Jae-Hong, Hwang, Seung Sik, Choi, Jae-Man, Sun, Yang-Kook, Kim, Hansu, Scrosati, Bruno & Kim, Dong-Won 2012 , 'Composite gel polymer electrolytes containing core-shell structures $SiO_2(Li^+)$ particles for lithium-ion polymer batteries', Electrochemistry Communications, vol. 17, pp. 18-21.

Li, Zikun & Tang, Tongbar 2010, 'High temperature thermal behaviours of XH_2PO_4 (X = Cs, Rb, K, Na) and LiH_2PO_3', Thermochimica Acta, vol. 501, issues 1-2, pp. 59-64.

Liang, Yinzheng, Ji, Liwen, Guo, Bingkun, Lin, Zhan, Yao, Yingfang, Li, Ying, Alcoutlabi, Mataz, Qiu, Yiping & Zhang Xiangwu 2011, 'Preparation and electrochemical characterization of ionic-conducting lithium lanthanum titanate oxide/polyacrylonitrile submicron composite fiber-based lithium-ion battery separators', Journal of Power Sources, vol. 196, issue 1, pp. 436–441.

Lim, Yu-Jeong, An, Yu-Ha & Jo, Nam-Ju 2012, 'Polystyrene – Al_2O_3 Composite Solid Polymer Electrolyte for lithium secondary battery', Nanoscale Research Letters, vol. 7, pp. 19.

Lubben, D & Modine, FA 1996, 'Enhanced ionic conduction mechanisms at LiI/Al_2O_3 interface', Journal of Applied Physics, vol. 80, issue 9, pp. 5150-5157.

Manthiram, Arumugam, Fu, Yongzhu & Su, Yu-Sheng 2013, 'Challenges and Prospects of Lithium Sulfur Batteries', Accounts of Chemical Research, vol. 46, no. 5, pp. 1125–1134.

Nagel, R, Grob, TW, Gunther, H & Lutz, HD 2002, '^6Li and ^7Li MAS NMR Studies on Fast Ionic Conducting Spinel-Type Li_2MgCl_4, $Li_{2-x}Cu_xMgCl_4$, $Li_{2-x}Na_xMgCl_4$, and Li_2ZnCl_4', Journal of Solid State Chemistry, vol. 165, issue 2, pp. 303-311.

Neves, Silmera & Fonseca, Carla P 2004, 'Mixed solid device based on conducting polymer composite and polymer electrolyte', Journal of the Brazilian Chemical Society, vol. 15, no. 3, pp. 395-399.

Noorussaba & Ahmad, Afaq 2011, 'Phase transition study in a [Cu_2HgI_4:0.2AgI] mixed composite system doped with K_2SO_4', Ionics, vol. 17, issue 8, pp. 759–766.

Noorussaba & Ahmad, Afaq 2012, 'Preparation, Characterization of a New Fast Ionic Conductor [Ag_2CdI_4:0.x AgI]', Analytical and Bioanalytical Electrochemistry, vol. 4, no. 6, pp. 621-634.

Noorussaba & Ahmad, Afaq 2013, 'Phase transition in a [Ag_2HgI_4:0.2AgI] mixed composite system doped with KI', Russian Journal of Electrochemistry, vol. 49, issue 11, pp. 1065-1072.

Pandey, GP, Kumar, Yogesh & Hashmi, SA 2010, 'Ioninc liquid incorporated polymer electrolytes for supercapacitors application', Indian Journal of Chemistry, vol. 49A, pp. 743-751.

Panero, S, Scrosati, B, Sumathipala, HH & Wieczorck, W 2007, 'Dual composite polymer electrolytes with enhanced transport properties', Journal of Power Sources, vol. 167, issue 2, pp. 510-514.

Park, Chang Hyun, Kim, Dong Won, Prakash, Jai & Sun, Yang-Kook 2003, 'Electrochemical stability and conductivity enhancement of composite polymer electrolytes', Solid State Ionics, vol. 159, issues 1-2, pp. 111 – 119.

Pitawal, HMJC, Dissanayake, MAKL & Seneriratne, VA 2007, 'Combined effect of Al_2O_3 nano fillers and EC plasticizer on ionic conductivity enhancement in the solid polymer electrolyte $(PEO)_9$ LiTF', Solid State Ionics, vol. 178, no. 13-14, pp. 885-888.

Rosseinsky, David R & Malpas, Ricard E 1975, 'Conductivity and rectification in metal halide intervalence mixtures', Nature, vol. 258, pp. 314 – 315.

Saba, Noorus & Ahmad, Afaq 2012, 'Preparation and Calculation of Various Ionic Transport Properties in a Superionic Mixed Composite System [Cu_2HgI_4:0.2 AgI]:0.xCuI', Analytical and Bioanalytical Electrochemistry, vol. 4, no. 1, pp. 83 – 95.

Saba, Noorus, Ahmad, Afaq & ÖZÇELİK, Bekir 2010, 'Study of phase transition in a [$CdHgI_4$:0.2AgI] mixed conducting composite system doped with KI and K_2SO_4', National Symposium on Recent Trends in Chemical Sciences: NSRTCS, A. M. U. Aligarh, pp. 1–12.

Shahi, K & Wagner, Jr JB 1982, 'Enhanced ionic conduction in dispersed solid electrolyte systems (DSES) and/or multiphase systems: AgI/Al_2O_3, AgI/SiO_2, AgI/Fly ash, and AgI/AgBr', Journal of Solid State Chemistry, vol. 42, issue 2, pp. 107–119.

Shekhon, SS 2003, 'Conductivity behaviour of polymer gel electrolytes: Role of Polymer', Bulletin of Materials Science, vol. 26, issue 3, pp. 321-328.

Song, JY, Wang, YY & Wan, CC 2000, 'Conductivity study of porous plasticized polymer electrolytes based on poly (vinylidene fluoride) a comparison with polypropylene separators', Journal of the Electrochemical Society, vol. 147, issue 9, pp. 3219-3225.

Souza, VC & Quadri, MGN 2013, 'Organic-Inorganic Hybrid Membranes in Separation Processes: A 10-Year Review' Brazilian Journal of Chemical Engineering, vol. 30, no. 04, pp. 683–700.

Sreelalitha, K & Thyagarajan, K 2013, 'Electrical Properties of Pure and Doped (KNO_3 & $MgCl_2$) Polyvinyl Alcohol Polymer Thin Films', International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS), vol. 3, issue 4, pp. 308-312.

Srivastava, Neelam & Tiwari, Tuhina 2009, 'New trends in polymer electrolytes: a review', E-Polymer, Vol. 9, issue 1, pp. 1738-1754.

Stephan, MA & Nahm KS 2006, 'Review on composite polymer electrolytes for lithium batteries', Polymer, vol. 47, issue 16, pp. 5952-5964.

Takashahi, H, Rikitake, N, Sakuma, T & Ishii, Y 2004, 'Origin of FSDP in superionic AgI–Ag_2O–V_2O_5 glasses', Solid state Ionics, vol. 168, issues 1-2, pp. 93-98.

Tarascon, JM & Armand, M 2001, 'Issues and challenges facing rechargeable lithium batteries', Nature, vol. 414, no. 6861, pp. 359-367.

Tripathi, Bijay P & Shahi, Vinod K 2011, 'Organic – inorganic Nanocomposite polymer electrolyte membranes for fuel cell applications', Progress in Polymer Science, vol. 36, issue 7, pp. 945-979

Varshney, P, Deepa, M, Agnihotry, SA & Ho, KC 2003, 'Photo-polymerized films of lithium ion conducting solid polymer electrolyte for electrochromic windows (ECWs)', Solar Energy Materials and Solar Cells, vol. 79, issue 4, pp. 449-458.

Varshney, Pradeep & Gupta, Shikha 2011, 'Natural polymer based electrolytes for electrochemical devices – a Review', Ionics, vol 17, issue 6, pp. 479-483.

Yang, Min & Hou, Junbo 2012, 'Membranes in Lithium Ion Batteries', Membranes, vol. 2, issue 3, pp. 367-383.

Yang, Rui, Zhang, Shichao, Zhang, Lan & Liu, Wenbo 2013, 'Electrical properties of composite polymer electrolytes based on PEO-SN-$LiCF_3SO_3$', International Journal of Electrochemical Science, vol. 8, issue 8, pp. 10163 – 10169.

Zhang, Yongguang, Zhao, Yan, Sun, Kyung Eun & Chen, P 2011, 'Development in Lithium/Sulfur Secondary batteries', The Open Materials Science Journal, vol. 5, suppl. 1: M3, pp. 215-221.